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Technical Report

Sea Base to Treeline Connector Innovation Cell

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This paper details research performed at the Naval Surface Warfare Center, Carderock Division (NSWCCD) within the "Sea Base to Treeline Connector" Innovation Cell in the Center for Innovation in Ship Design (CISD). The primary objective of this Innovation Cell was to develop a new concept that looks at the problem of moving military vehicles, troops, and equipment from the Sea Base to the treeline. This process includes moving the cargo off the cargo transport ship at the Sea Base, moving the cargo to the beach, and then moving the cargo over the beach to some distance inland that is road or rail accessible. The Innovation Cell brainstormed and identified many concepts to solve the problem and made use of other interested parties in the brainstorming process. Several initial concepts were researched, including both near-term and long-term solutions. These concepts ranged from large innovative vehicles to systems of smaller vehicles including existing military assets. Advantages and disadvantages of each concept were assessed, and a final concept was selected for further design work. Key decision factors were sea state capability and fuel consumption, as well as projected cost, risk, and effectiveness. Payload requirements and other necessary operational capabilities were used to establish an event model for the selected concept. This event model was then used to determine initial approximations of system characteristics. Basic hullform, arrangements, weights, hydrostatics, and power analyses were then performed to evaluate the feasibility of the new concept.

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Abstract

This paper details research performed at the Naval Surface Warfare Center, Carderock Division (NSWCCD) within the "Sea Base to Treeline Connector" Innovation Cell in the Center for Innovation in Ship Design (CISD). The primary objective of this Innovation Cell was to develop a new concept that looks at the problem of moving military vehicles, troops, and equipment from the Sea Base to the treeline. This process includes moving the cargo off the cargo transport ship at the Sea Base, moving the cargo to the beach, and then moving the cargo over the beach to some distance inland that is road or rail accessible. The Innovation Cell brainstormed and identified many concepts to solve the problem and made use of other interested parties in the brainstorming process. Several initial concepts were researched, including both near-term and long-term solutions. These concepts ranged from large innovative vehicles to systems of smaller vehicles including existing military assets. Advantages and disadvantages of each concept were assessed, and a final concept was selected for further design work. Key decision factors were sea state capability and fuel consumption, as well as projected cost, risk, and effectiveness. Payload requirements and other necessary operational capabilities were used to establish an event model for the selected concept. This event model was then used to determine initial approximations of system characteristics. Basic hullform, arrangements, weights, hydrostatics, and power analyses were then performed to evaluate the feasibility of the new concept.

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Dr. Colen G. Kennell
Mark J. Selfridge

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Introduction

The work described in this report was performed by the Center for Innovation in Ship Design (CISD) of the Ship Systems Integration and Design Department (Code 20) at the Naval Surface Warfare Center, Carderock Division (NSWCCD). The Office of Naval Research (ONR) provided funding. This Innovation Cell was conducted during a ten-week period in summer 2005.

Statement of Work

The primary objective of the "Sea Base to Treeline Connector" Innovation Cell was to start with a clean sheet of paper and look at the problem of rapidly moving military vehicles, personnel, and equipment from the Sea Base to the treeline (Figure 1). The treeline is defined as some distance from the waters edge that is road or rail accessible or that is clear of beach obstacles so that all wheeled and tracked vehicles are operable. The "Sea Base to treeline" mission is composed of three main components:

1. Moving the cargo off of the cargo transport ship at the Sea Base.
2. Moving the cargo to the beach (assuming a distance of 25 nm).
3. Moving the cargo from the beach, over the beach, and to the treeline (assuming a distance of 100 yards).

The new concept must complete these three mission components in approximately eight hours or less (cover of darkness). However, these three mission components do not have to be done by one vehicle, and the new concept may also make use of existing assets in the United States military's inventory.

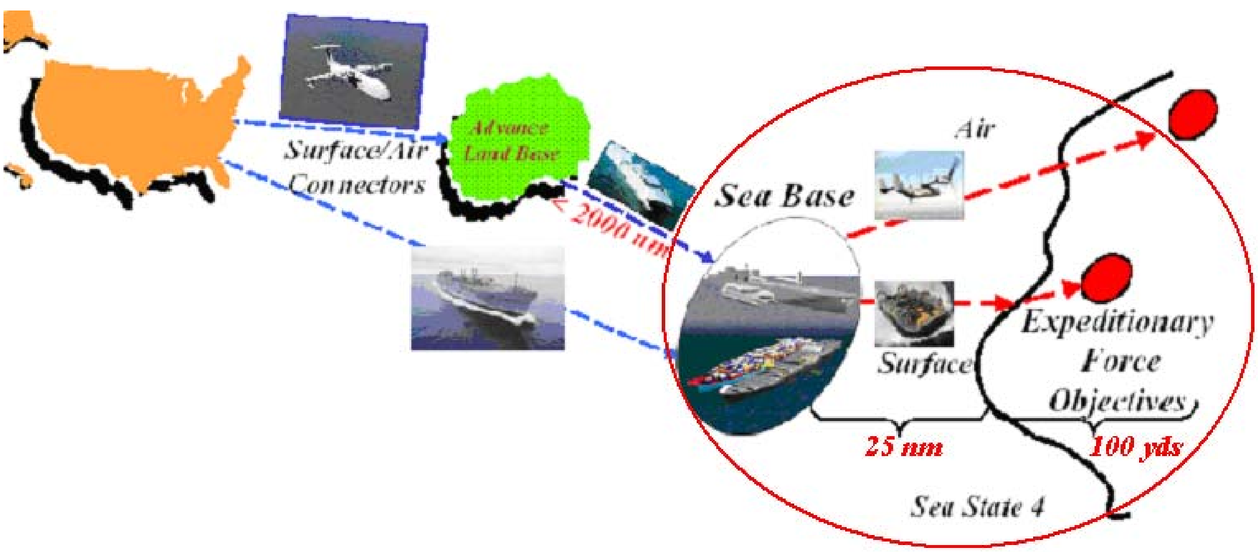

Figure 1 - Innovation Cell Focus

Mission Definition

Payload

The assumed cargo to be moved is the surface element of a projected 2015 Marine Expeditionary Brigade (MEB) developed by Marine Corps Combat Development Command. This includes personnel, wheeled and tracked vehicles, and other equipment as described in Table 1. The cargo listed in Table 1 is currently transported by the LCAC, and this MEB was provided to the Center for Naval Analysis (CNA) for use in another LCAC-related study. Based on this study, it was determined that it would take 96 LCAC sorties to transport the cargo to the beach. It was also determined that it would take approximately 20 LCAC vehicles to deliver the MEB from the Sea Base to the treeline in eight hours.

The items listed in Table 1 total to approximately 5,800 metric tons of cargo and a footprint area of 17,000 m^2. More detailed payload characteristics can be found in Appendix A. With the exception of the Q46 (fire finder radar), all equipment is currently in the USMC inventory. Q46 introduction data was unavailable, so similar radar data was used as a substitute.

Table 1 - MEB Assault Element Table of Organization and Equipment

UNIT	PERSONNEL	HMMWV	MRC	TRLR M390	FORKLIFT	MTVR	M198	LVS MK48	M1A1 TANK	M88	AVLB	MEWSS	AAAV	Q46	ABV	LAV
1 INFBN (REIN)	1,018	55	13	-	-	-	-	-	-	-	-	-	48	-	2	-
3 D/S BTRY	330	15	12	24	3	42	18	-	-	-	-	-	-	-	-	-
1 ARTY Q46 DET	8	4	-	-	-	-	-	-	-	-	-	-	-	4	-	-
1 LAR CO	133	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25
1 TANK CO	85	4	1	-	-	-	-	-	14	1	-	-	-	-	-	-
1 TANK CO H&S DET	35	-	-	4	-	6	-	1	-	-	1	-	-	-	-	-
1 AAV CO	200	-	1	1	-	3	-	-	-	-	-	-	-	-	-	-
1 AAV CO H&S DET	35	2	-	-	-	3	-	-	-	-	-	-	-	-	-	-
1 CSS DET	178	6	3	-	4	67	-	1	-	-	-	-	-	-	-	-
1 RADBN DET	98	7	-	6	-	6	-	-	-	-	-	3	-	-	-	-
1 CE SRI DET	76	6	-	6	-	6	-	-	-	-	-	-	-	-	-	-
1 CE COMM DET	30	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	2,226	99	33	41	7	133	18	2	14	1	1	3	48	4	2	25

Projected Operational Environment

The new concept is expected to function in either a Sea Base environment or in conjunction with a shuttle ship. A Sea Base is envisioned as a collection of ships and

other platforms at least 25 nautical miles from a shore that supports military littoral missions. A few objectives of seabasing include minimizing the operational reliance on shore infrastructure, enhancing afloat positioning of joint assets, integrating joint logistics, and improving vertical delivery methods.

The operating environment is anticipated to be a sensitive littoral region, close-in. At sea, the new concept is likely to encounter underwater obstacles such as mines and reefs. It also must be operable through sea state four, which is defined as 4-8 foot waves, 17-21 knot winds, and an 8.8 second average modal wave period. The beach is projected to be an unimproved beach similar in conditions to that which an LCAC can fly on. This includes 20-foot ditches, five-foot vertical obstacles, ten-degree gradients, mud, swamps, etc. The beach can also be assumed to be secure, but in a hostile environment (i.e. the EFVs have landed and secured a beachhead).

Requirements Summary

In order to define the "Sea Base to treeline" mission in greater detail, the following assumptions were made:

- Cargo transfer capabilities available at Sea Base (ramps, platforms, cranes, etc.)
- Sea Base located 25 nm from coastline
- Treeline located 100 yards inland
- Payload – MEB Surface Element (See Table 1)
- Sea States 0-4
- Unimproved Beach
- Secure beach, but in a hostile environment

These assumptions along with the mission requirements are summarized in Figure 2.

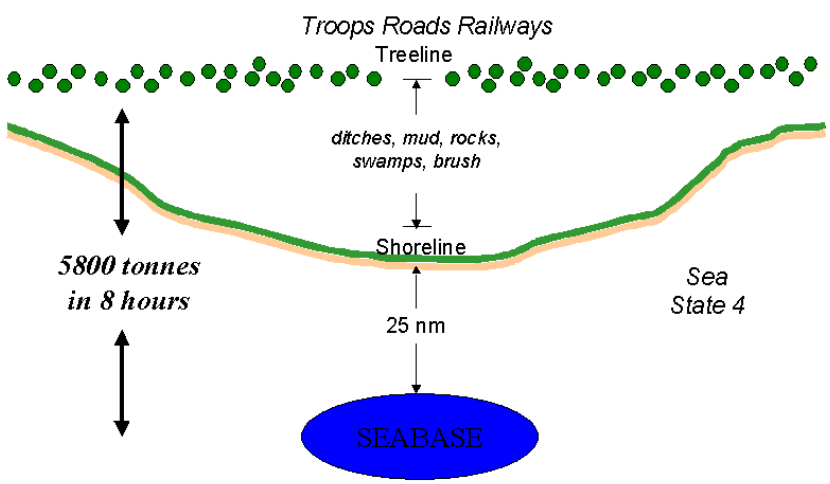

Figure 2 – Requirements Summary

Current Method - LCAC

The MEB surface element is currently transported by the LCAC (Landing Craft, Air Cushioned) (Figure 3). The LCAC is a high speed, over-the-beach, fully amphibious, air cushion landing craft capable of carrying a 60-75 ton payload. With a full payload, it can

exceed speeds of 50 knots in sea state two, and 40 knots in sea state three. Overloaded, it can still achieve 30 knots in sea state two. The LCAC is unconstrained by winds, tides, underwater obstacles, and unimproved beaches. Ashore, it has the capability to cross 20-foot ditches and five-foot vertical obstacles, knock down small trees, and climb 10-degree gradients. These capabilities allow the LCAC to assault 73% of the world's beaches versus only 17% for conventional landing craft.

However, the LCAC does have a few limitations. As mentioned earlier, it was determined that it would take 96 LCAC sorties to transport the assumed payload to the treeline. This means that it would take approximately 20 LCAC vehicles operating between the Sea Base and the treeline to complete the mission in eight hours. Other LCAC limitations include its high acquisition and operational costs, high fuel consumption, and sea state restrictions. As a result, these factors were critical in selecting a new "Sea Base to treeline" concept.

Figure 3 - LCAC Offloading at Treeline

Approach

At this point in the project, the "Sea Base to treeline" mission was broken down into two separate components:

1. Sea Base to Beach – involves transporting the payload from the Sea Base to a distance just off the beach.
2. Beach to Treeline – involves transporting the payload from just off the beach, over-the-beach, and to the treeline.

Using these two separate mission components, three types of connector concepts were researched:

1. Sea Base to Beach Connector
2. Beach to Treeline Connector
3. Sea Base to Treeline Connector

The first two connector types only deal with one of the two mission components and thus must be used in combination with each other. "Sea Base to Treeline" connectors are vehicles that are capable of transporting the payload from the Sea Base to the treeline directly. This is illustrated in Figure 4.

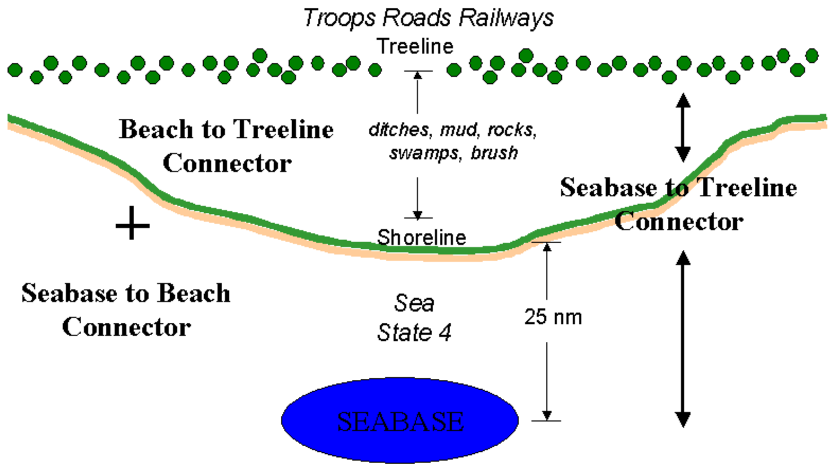

Figure 4 - Innovation Cell Direction

There were several important "decision factors" behind the selection of a new "Sea Base to treeline" concept. These decision factors included:

- Throughput Rate (tonnes delivered per hour): All new concepts should exhibit an ability to move large amounts of cargo in a short period of time. The total mission should be completed in 6-8 hours. A time greater than eight hours does not meet the mission requirement; a time below six hours would imply the new concept is "over-designed."
- Sea State Capability: The new concept should be operable through sea state four.
- Terrain Capability: The new concept should be able to handle ditches, mud, rocks, swamps, brush, and ten-degree gradients when traveling on land.
- Fuel Consumption: Concept fuel consumption should be reduced from current LCAC consumption.
- Cost: The new concept should have a low acquisition and operational cost. Cost does not include the cargo, but should include any enablers at either end.
- Technology: Solutions should be robust (industrial-strength) with non-exotic technology. Innovative concepts are encouraged as long as the concept is still practical and the science and technology issues can be addressed.

The goal in the decision process is to maximize effectiveness, while minimizing both cost and risk.

Innovation Cell Team

An Innovation Cell was formed under CISD located at NSWCCD. The cell had a designated Team Leader who was located in the team room and had overall responsibility for the Innovation Cell activities. The Team Leader reported to the CISD Director of Operations. In addition to the Team Leader, the Innovation Cell consisted of two full-time student interns, as well as mentors and guidance from senior navy engineers as necessary (Table 2).

Table 2 - Innovation Cell Team

Team Members	Field	School
Jesse Chafin	Ocean Engineering	Florida Atlantic University
Nathan Good – Team Leader	Ocean Engineering	Virginia Tech
Nicholas Milbert	Mechanical Engineering	University of Maryland
Mentors	**Organization**	**Code**
Jeffrey Hough	NSWCCD	202
Dr. Colen Kennell	NSWCCD	242
LCDR Russell Peters	NSWCCD	2002
Mark Selfridge	NSWCCD	24

Industry contacts also assisted with the work of this Innovation Cell. CDI Marine/BLA and Hovertrans provided hover barge design guidance, while Aerojet, AeroTech, ATK, and Orbital Sciences Corporation provided commercial rocket data. Dr. Pramud Rawat also contributed to this Innovation Cell as a consultant in aerostat design.

Analysis Tools

Computational and modeling tools used in this project are listed in Table 3.

Table 3 - Analysis Tools

Analysis	Tool
Arrangements	Rhino 3D
Concept Animation	Bryce 5, Studio 7
Hullform Development	Rhino 3D
Hydrostatics	MaxSurf - HydroMax
Programming	MATLAB
Resistance/Power	MaxSurf – HullSpeed, ASSET

Alternatives

Sea Base to Beach Connectors

"Sea Base to Beach" connectors are concepts that transport cargo from the Sea Base to the beach or a small distance just off the beach. "Beach to Treeline" connectors are required in combination with "Sea Base to Beach" connectors to transport the cargo the remaining distance to the treeline. Both existing and new concepts were explored, and they are described in the following sections. It should be noted here that air solutions were briefly considered in this project, but were eliminated due to their inability to deliver large payloads without a runway at the Sea Base as well as other inefficiencies when compared to the other concepts.

Existing Concepts

Logistics Support Vessel

The Logistics Support Vessel (LSV) is the Army's largest powered watercraft and is capable of carrying up to 2,000 tons of cargo from sealift ships to shore during operations (Figure 5). The LSV is designed to transport heavy, outsized cargo such as ISO containers, and it has bow and stern ramps to enable drive through capabilities for RORO operations. The LSV also has a hullform with a sloped keel to enable itself to "beach" on select shores. However, beach operations are limited to two-degree gradient beaches with a reduced payload, and the LSV's slow speed of 11.5 knots (loaded) decreases its throughput rate.

Figure 5 - Logistics Support Vessel (LSV)

Surface Effect Ships

A Surface Effect Ship (SES) is a vessel with rigid side hulls and air cushion support. Air cushion support reduces the wetted surface area of the ship, which in turn reduces the frictional resistance of the ship. This results in a ship capable of traveling at higher speeds with the same installed power. Partial air cushion support also reduces the draft of the ship, allowing the vessel to operate in shallow littoral regions. Disadvantages of SES vessels include their payload limitations and high cost. Existing SES concepts include an air-assisted LSV and a partial air cushion supported catamaran (PACSCAT[5]). These concepts offer decreased drafts and increased speeds over non-air cushion supported alternatives such as the LSV. Variations of these concepts include SES vessels with retractable skirts (or no skirt at all) and tracked hulls.

Heavy Lift Ships

Heavy Lift Ships (HLS) are large, semi-submersible ships with large open decks used to carry extremely heavy payloads. An example of a HLS is the MV Blue Marlin (Figure 6), which has an 11,000 m^2 deck area and is capable of lifting 70,000 tons. Heavy Lift Ships are attractive options because of their large lifting capacity; however, this presents the problem of essentially transporting the entire Sea Base to shore and increasing vulnerability. Other disadvantages include slow speeds and poor roll periods in the ballasted condition.

Figure 6 – MV Blue Marlin

Shallow Draft High Speed Ships

Shallow Draft High Speed Ship (SDHSS) is a term used to classify ships that travel at high speeds (40-50 knots) with a low draft (approximately 10 feet). SDHSS vessels are typically multi-hulls to achieve the low drafts necessary for beach operations. Existing SDHSS concepts are 5,000 ton payload vessels with ranges in excess of 10,000 nautical miles. However, a high-speed multi-hull of this size is still a relatively far term technology since most current shipyard dry docks cannot support the large beam requirements.

New Concepts

Multi-Hull Heavy Lift Ships

Combining HLS and multi-hull technology addresses many of the issues associated with the monohull HLS. Multi-hulled vessels offer decreased drafts and lower resistance, resulting in increased speeds. This decreased draft also allows the vessel to operate closer to the coast. Roll problems and other seakeeping issues are kept to a minimum due to the increased transverse stability of multi-hulled vessels. Another advantage of a multi-hulled HLS is the potential to increase cargo capacity due to the large cross decks normally linked to catamaran and trimaran designs. A conceptual trimaran HLS is shown below (Figure 7).

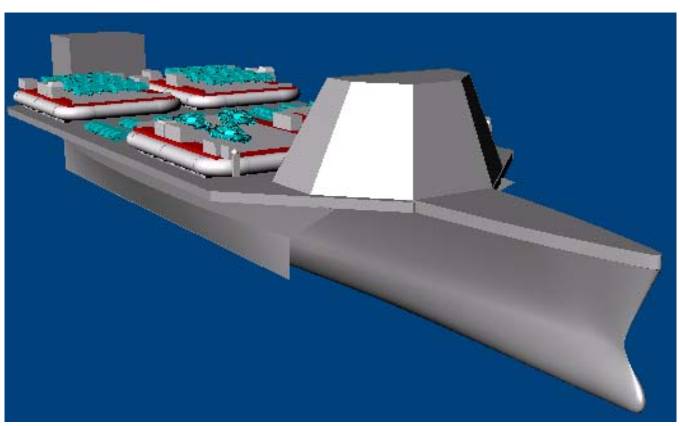

Figure 7 - Trimaran HLS Concept

Double Decker HLS

The Double Decker HLS (DDHLS) concept is essentially a monohull HLS with a second lifting deck and increased ballasting capabilities (Figure 8). The decks are loaded and unloaded by ballasting to the desired waterline and using other amphibious craft (such as air cushion vehicles) to transport the payload. This concept better suits payloads with large footprint areas by providing twice the deck space of a conventional HLS.

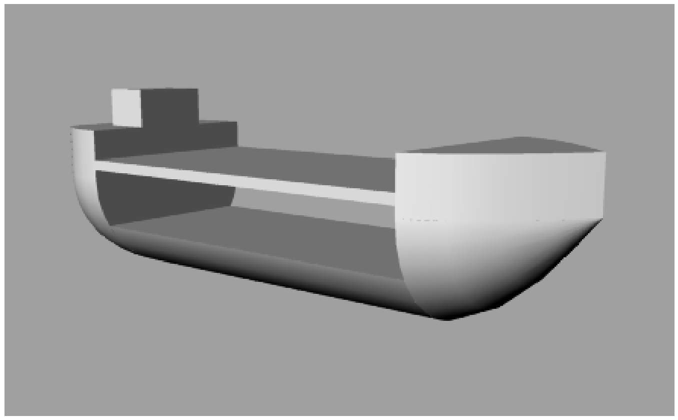

Figure 8 - DDHLS Concept

Trimaran with Hinged or Detachable Center Hull

Two new and innovative trimaran concepts were investigated: the hinged trimaran concept and the detachable causeway concept. The hinged trimaran concept is illustrated in Figure 9 and involves three steps. The first step involves transporting cargo from the Sea Base to just off the beach in the trimaran configuration. The second step involves rotating the fore end of the center hull upward to follow the local beach gradient. Finally a ramp is extended and RORO cargo is rolled directly onto the beach. Cargo may be stored in the center hull for direct delivery or on the cross deck. This design was not considered further due to the science and technology issues related to a hinged hull design.

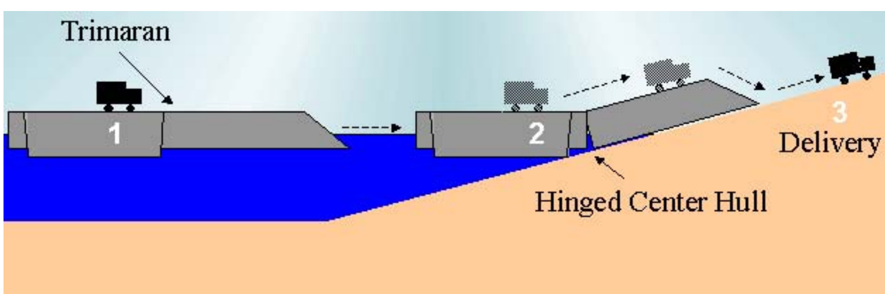

Figure 9 - Hinged Trimaran Concept

The second trimaran concept is the detachable causeway concept (Figure 10). This concept is similar to the hinged trimaran concept in that the first step involves transporting cargo from the Sea Base to just off the beach in the trimaran configuration. The second step however involves beaching the center hull using wheels or a track system to create a "causeway" to offload cargo. Once the cargo is offloaded, the center

hull detaches, and the unloaded catamaran returns to the Sea Base. The center hull now serves as a delivery point for other loaded catamarans to dock and unload cargo. This design was also eliminated from consideration due to high science and technology requirements.

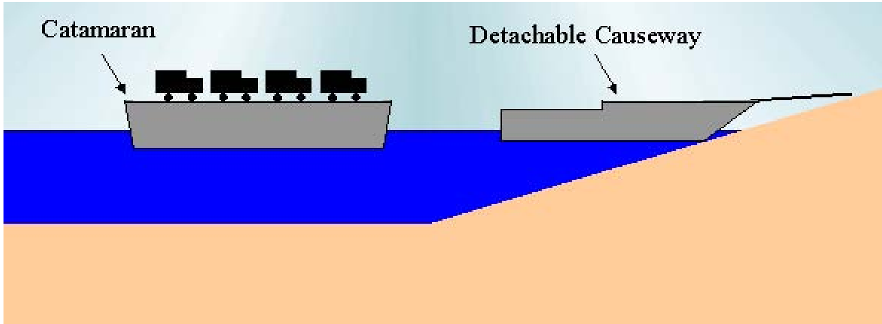

Figure 10 - Detachable Causeway Concept

Beach to Treeline Connectors

"Beach to Treeline" connectors are concepts that transport cargo from just off the beach, over-the-beach, and to the treeline. "Sea Base to Beach" connectors are required in combination with "Beach to Treeline" connectors to complete the Sea Base to treeline mission. Both existing and non-existing concepts were explored, and they are described in the following sections.

Existing Concepts

Inflatable Aerostat

An existing "Beach to Treeline" connector concept is the inflatable aerostat. An inflatable aerostat is a tethered balloon propelled by a pulley-winch system used to transport small payloads a small distance. An example of inflatable aerostat technology is "balloon logging," a method of transporting fallen logs using hot-air balloons and a pulley-winch system. "Balloon logging" (Figure 11) was employed quite heavily in the Pacific Northwest during the 1970s and 1980s, and it is currently being used in Russia. This system is used in areas where it is difficult to transport fallen trees, such as steep hills or mountains, and in areas where vehicles are not allowed to drive on the forest floor to pick up timber.

There are several limitations of inflatable aerostat technology however. For example, the hot-air balloons used in "balloon logging" systems can only support a load of about 5 tons. Inflatable aerostats cannot support larger loads due to their lack of any rigid or semi-rigid internal structure. To support the MEB surface element, semi-rigid airships would need to be used instead. Other limitations of inflatable aerostat technology include the extensive setup time required for the pulley-winch and cable system as well as the low operating speed, reducing the overall throughput rate. Due to these limitations, inflatable aerostats were not considered for this mission.

Figure 11 - Balloon Logging

Hover Barge

A hover barge is an amphibious air cushion vehicle designed to carry large payloads over both water and land. Hover barges can access areas that would otherwise be un-accessible to conventional landing craft and terrain vehicles. Hover barges are not self-propelled; current designs must be towed or winched ashore. Figure 12 displays a hover barge being towed by a tractor with large tires. Rolligon Corporation currently has tractors with large tires in order to distribute weight over a greater area and lower ground contact pressure to approximately 3 psi. Reduced ground contact pressure enables tractors to be driven on soft soil and other surfaces that conventional terrain vehicles would sink into. Due to their lack of propulsion systems, hover barges are limited in range, and a winched version would also require some beach preparation.

There have been a few hover barges designed and built. For example, the Hovertrans "Sea Pearl" is a 250 ton payload sea going commercial hovercraft, capable of three-meter wave heights. Hovertrans is also currently designing a 330 ton payload hovercraft to be used for drilling in swamps.

Figure 12 - Hover Barge

New Concepts

Self-Propelled Hover Barge

A new variation of the hover barge concept is the self-propelled hover barge. The self-propelled hover barge is a dual propulsion (water and land) air cushion vehicle that supports a large payload. Self-propelled hover barges could use air screws or propellers

for over-the-water propulsion, and they could use wheeled or tracked systems for over-the-beach propulsion. Similar studies have already been performed regarding the feasibility of such a concept, including a 1985 BLA project referred to as LAMP-H (Lighter Amphibious, Heavy-Lift). Hovertrans is also investigating the possibility of a self-propelled hover barge.

Aerostat Elevator

The aerostat elevator is another innovative concept that makes use of inflatable aerostat technology for the means of transporting cargo. The concept involves a large inflatable aerostat anchored to a shuttle ship just off the beach with a suspended cable system connected to supports at the treeline (Figure 13). The aerostat inflates at the shuttle ship and lifts payload platforms high enough to generate the required potential energy to glide the platforms along the cable system to the treeline. This concept is gravity driven and does not require a propulsion system. However, the aerostat elevator concept faces the same limitations as the "balloon logging" concept. As discussed earlier, inflatable aerostats cannot support larger loads due to their lack of any rigid or semi-rigid internal structure. To support the MEB surface element, semi-rigid airships would need to be used for lift instead. An aerostat elevator with inflatable aerostats is more suitable for smaller payload missions such as humanitarian aid. Also, inflatable aerostats perform unpredictably in adverse weather, and the dynamics of such a large cable system present science and technology challenges. Due to these limitations, the aerostat elevator was not considered for further design work.

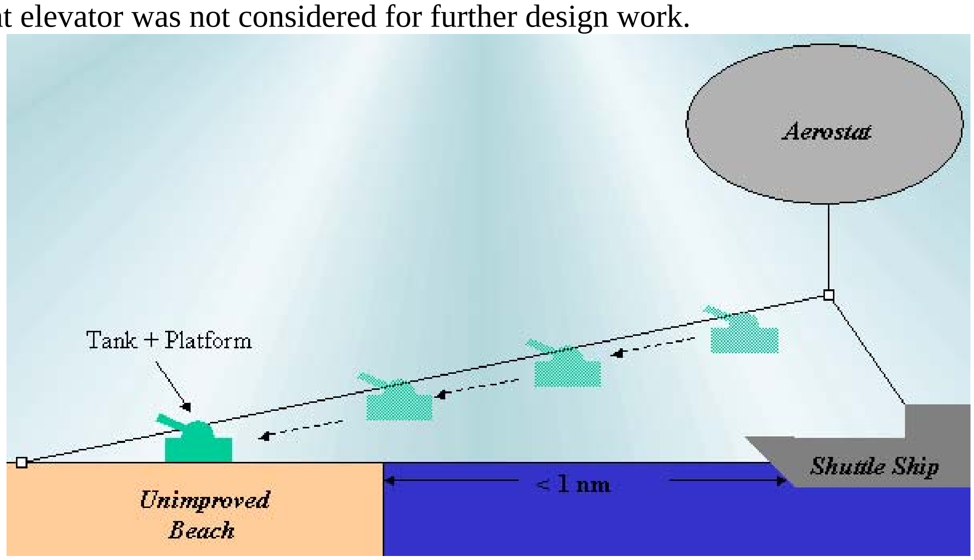

Figure 13 - Aerostat Elevator Concept

Solid-Fuel Rocket Lifted Platform

The solid-fuel rocket concept is a loaded platform that is lifted and propelled by commercial rockets (Figure 14). The goal of the concept is to transport a large payload (ex. M1A1 Tank) a short distance (~¼ mile) in a short period of time (~30 seconds). The platform is lifted by rockets 10-20 feet off the ground and then propelled forward by secondary rockets to the treeline. The concept was researched, and it was established that it would take approximately 10 tons of propellant to transport a 70 ton payload for 30 seconds using Aerotech RMS 98/15360 rockets. A cost estimate of over $2 million per launch deemed the concept unfeasible, and it was not researched further. Other

complications of the design included the creation of large plumes of smoke and potential danger to personnel.

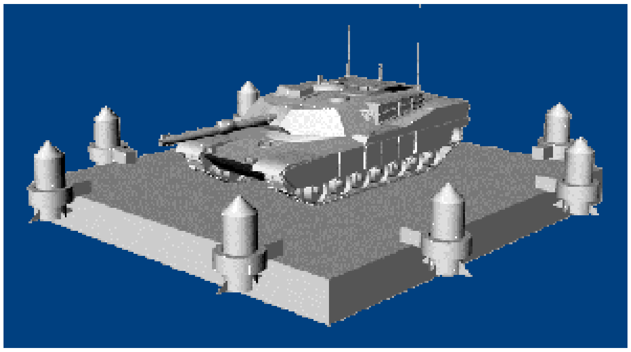

Figure 14 - Solid-Fuel Rocket Lifted Platform

Rapid Beach Preparation Options

Other new "Beach to Treeline" connector concepts involve rapid beach preparation. Some of these concepts include:

- Canal Dredging Concept
- A-Frame Roadway Concept
- Skid/Pulley/Winch System
- Conveyer Belt Concept
- Railroad Concept

The "Canal Dredging Concept" involves rapidly creating a canal from the beach to the treeline for cargo ships to dock. This process is made possible through the use of commercial dredging boats, such as the *Vasco da Gama* (Figure 15), which can dredge 33,000 m^3 per hour.

Figure 15 - Vasco da Gama Dredger

Such a dredger could also be used to create a trench for the "A-Frame Roadway Concept." The A-Frame Roadway Concept is basically a modular roadway placed in a trench located between the shoreline and the treeline. The concept gets its name from its cross-sectional shape, as shown in Figure 16. During installation, the "A" would be

inverted and placed in the trench. A shuttle ship and ramp could then be used to provide a platform for delivering cargo all the way to the treeline.

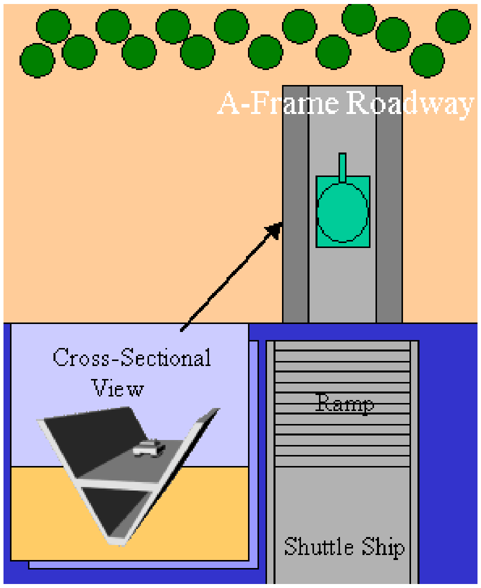

Figure 16 - A-Frame Roadway Concept

The remaining three concepts are the Skid/Pulley/Winch System, Conveyer Belt Concept, and Railroad Concept (F). The "Skid/Pulley/Winch System" involves a reduced friction tarp laid out on the beach and lubricated with seawater. Flat-bottom barges called

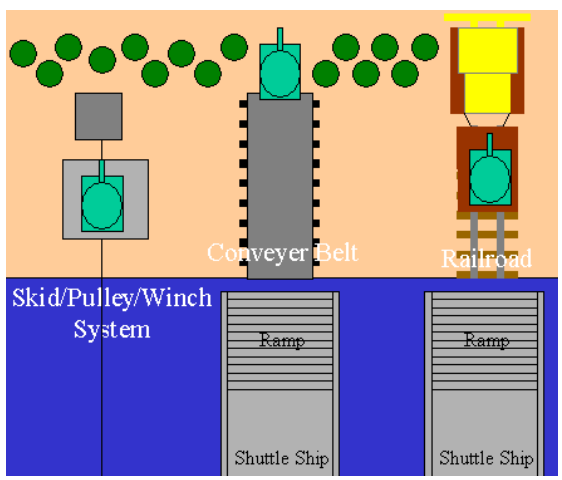

Figure 17 - Rapid Beach Preparation Options

"skids" are then pulled across the smooth surface using a pulley/winch system. The "Conveyer Belt Concept" involves a diesel-powered conveyer belt extending from the shoreline to the treeline. A shuttle ship and ramp could then be used to provide a platform for delivering cargo all the way to the treeline. Finally, the "Railroad Concept" requires modular tracks to be transported to the beach using amphibious vehicles. Once assembled, train cars are placed on the tracks and used as "Beach to Treeline" connectors between loaded shuttle ships and the treeline. All of these beach preparation options

reduce the covertness of the mission, and they are limited because of the set-up time required. These options were also found to be inferior to other "Beach to Treeline" connectors, and thus were not considered for further design work.

Sea Base to Treeline Connectors

"Sea Base to Treeline" connectors are concepts that are capable of transporting the payload from the Sea Base to the treeline directly. Only two such connectors were investigated in this study: the LCAC and semi-rigid airships. The LCAC is the Navy's current method of delivering cargo from the Sea Base to the treeline. Semi-rigid airships are a new "Sea Base to Treeline" connector concept.

Airship transportation is advantageous over conventional land transportation systems because there are no terrain limitations and much higher speeds and ranges are achievable. In recent years, airship companies have resurfaced and improved the technology behind semi-rigid air vehicles. The CargoLifter and World SkyCat companies are currently designing and building airships for the purpose of transporting heavy, bulky payloads. Some semi-rigid airship data is displayed in Table 4, and the World SkyCat 220 is displayed in Figure 18.

Semi-rigid airships could be used to lift a large payload at the Sea Base and then deliver it directly to the treeline. However, airships are limited by their large size. As a general rule of thumb, helium provides four pounds of lift per 100 cubic feet. This means that in order to lift a 100 ton payload, it would take an airship the size of the Hindenburg. This equates to roughly five million cubic feet of helium. Hydrogen could be used to increase lift capacity, but it has the downfall of being highly flammable. The long ranges of airships would also be better suited for longer, inter-theater missions. Due to these characteristics, semi-rigid airships were not considered further.

Table 4 - Semi-Rigid Airship Data

Parameter	CargoLifter CL-160	World SkyCat 220
Length	260 m	185 m
Width	65 m	77 m
Cruise Speed	70 knots	80 knots
Range	5,400 nm	3225 nm
Payload	160 tons	220 tons

Figure 18 - World SkyCat 220

Trade-Off Study

Since no feasible "Sea Base to Treeline" connector was found, it was determined that a system of a "Sea Base to Beach" connector and a "Beach to Treeline" connector was required. To select this system, a comparison matrix was set up for each set of connectors. Within these matrices, concepts were qualitatively ranked in categories such as throughput rate, beach preparation, cost, risk, and survivability. These categories were also weighted to reflect the mission and used to determine an overall measure of effectiveness (OMOE) for each concept. OMOEs ranged from 0-100, with 100 being the most effective. OMOE results are shown in Table 5 and Table 6. It was concluded that a system consisting of a Heavy Lift Trimaran (HLT) and Self-Propelled Hover Barge (SPHB) would be the most effective system. These two concepts were then developed in greater detail, and they are described in the following sections.

Table 5 - Sea Base to Beach OMOEs

Concept	OMOE
HLS – Trimaran	81
HLS – Catamaran	79
SDHSS	77
Air-Assisted LSV	75
HLS – Monohull	74
SES	69
DDHLS	69
Trimaran – Detachable CH Roadway	65
LSV	64
Trimaran – Hinged CH	60

Table 6 - Beach to Treeline OMOEs

Concept	OMOE
SPHB	76
Hover Barge	71
Skid/Pulley/Winch	64
Rolligon	63
Aerostat Elevator	62
Inflatable Aerostat	61
A-Frame Roadway	59
Canal Dredging	59
Rocket Platform	56
Conveyer Belt	54
Railroad	52

Selected System – Heavy Lift Trimaran & Self-Propelled Hover Barge

The selected “Sea Base to treeline” system was the Heavy Lift Trimaran (HLT) used in conjunction with the Self-Propelled Hover Barge (SPHB). These two concepts ranked the highest in the trade-off study, and they were developed further as described in the following sections.

CONOPS

The general concept of operations (CONOPS) for the HLT/SPHB system involves a HLT transporting fully loaded SPHBs and other wheeled and tracked vehicles from the Sea Base to just off the beach at a speed of 24 knots. The HLT will then fully ballast and heel slightly so that the SPHBs are able to hover off the ship and onto the water surface. The SPHBs then embark toward the shore at eight knots via a retractable marine screw system. Upon reaching the beach, the SPHBs retract their marine screws and deploy track systems to travel up the beach towards the treeline. The payload is unloaded, and the SPHBs then proceed back to the HLT to pick up the next load for delivery. Figure 19 shows the American Cormorant during similar operations.

Figure 19 - American Cormorant during Cargo Offload

Event Model

In order to determine principal characteristics of the HLT/SPHB system, an event model was constructed with the following independent and dependent variables:

- Independent Variables (Ranges):
  - Standoff Distance (4 nm) - This is the distance from the HLT to the shoreline. This variable was set as a constant four nautical miles as a worst-case scenario for SPHB operations.
  - Number of HLTs (1-6)
  - Number of SPHBs per HLT (1-4)

  - HLT Velocity (10-30 knots)
  - SPHB Velocity (5-15 knots)
- Dependent Variables:
  - SPHB Cargo Area
  - HLT Deck Area
  - Mission Time

The feasible design space was composed of variable combinations that resulted in a mission time between six and eight hours. The following parameters were then selected from this design space to maximize effectiveness and minimize cost and risk:

- 4 HLTs w/ 4 SPHBs per ship
- HLT Velocity – 24 knots
- SPHB Velocity – 8 knots
- HLT Deck Area – 6,000 m^2
- SPHB Cargo Area – 550 m^2
- 2 trips per SPHB (32 total trips)
- 2.6 hour round trips
- 6.5 hour total mission time (987 tons/hour)

These parameters were then set as the requirements for the HLT/SPHB system.

Heavy Lift Trimaran

Hullform

The implementation of a trimaran hullform with heavy lift technology is the next logical step in the evolution of heavy lift ship design. A trimaran hullform offers a large center hull to store ballast for semi-submersible operations, and side hulls increase transverse stability and enhance hydrodynamic properties. A traditional monohull HLS is plagued by both its low speed and poor roll period. The trimaran hullform overcomes these disadvantages by offering decreased hull resistance (i.e. increased speed) and improved seakeeping properties. The monohull HLS also lacks open deck area relative to its lifting capacity. For example, the MV Blue Marlin has the ability to lift about 460 tanks, but it only has deck space for 220 tanks. The large cross deck of a trimaran hullform allows for an increased payload area relative to its lifting capacity.

A modified Rapid Strategic Lift Ship (RSLS) center hull was used as the parent center hull for the HLT. Basic side hulls were then added and located to create a beam producible in any shipyard that can accommodate a beam of 40-45 meters. This includes Kvaerner Philadelphia and General Dynamics National Steel and Shipbuilding Company (NASSCO) in addition to Newport News. HLT hullform characteristics are displayed in Figure 20 and Table 7.

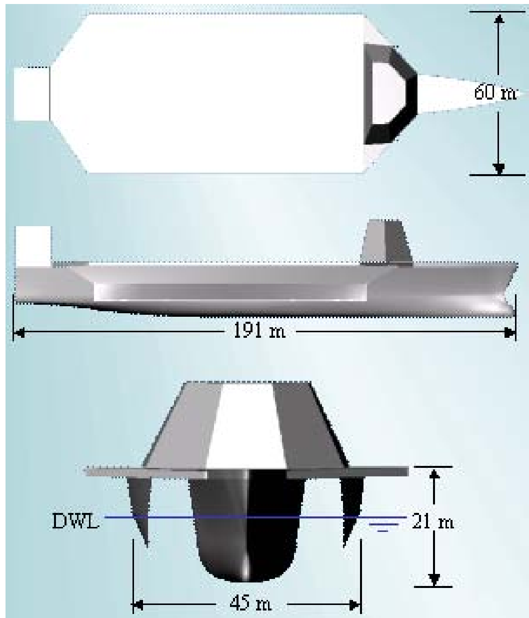

Figure 20 - HLT Hullform

Table 7 - HLT Hullform Characteristics

Parameter	Value
Length (Center Hull)	191 m
Length (Side Hulls)	127 m
Length (Open Deck)	103 m
Beam (Center Hull)	22 m
Beam (Side Hull to Side Hull)	45 m
Max Beam (Deck Edge to Deck Edge)	60 m
Depth (Overall)	21 m
Depth (Center Hull)	21 m
Depth (Side Hulls)	15 m
Design Draft	12 m
Cargo Area	6,000 m^2

The main driver in the HLT hullform design was the required cargo area of 6000 square meters. The general length and beam of the ship were configured to meet this large deck area requirement, and the deck edges were also extended laterally past the side hulls. Loads on the extended deck are supported by the side hull structure. A significant disadvantage of monohull HLS designs is the large amount of deck wash in the ballasted state. The extended deck of the HLT is able to reduce deck wash in the ballasted condition by listing slightly. If the raised deck edge is positioned to face incoming waves, it would eliminate a great deal of deck wash, and it would also reduce wave height on the other side of the ship. This enables safe loading and unloading of vehicles in increased sea states. A possible option would be to hinge the extended deck at its connection points with the side hulls (Figure 21). This would enhance the producibility of the vessel by decreasing the maximum beam of the ship. The hinged deck segments

could be raised when entering beam-restricted ports or used to protect cargo from deck wash at sea.

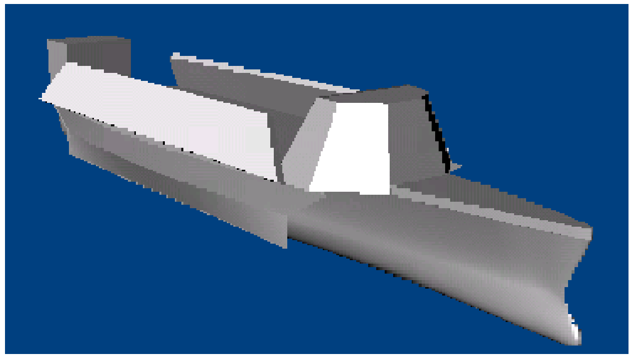

Figure 21 - Hinged Cross Deck Option

Deck Arrangement

The HLT deck arrangement is shown in Figure 22. There is enough deck space for four SPHB loading stations as well as the remaining payload (wheeled and tracked vehicles). A staging area for MEB surface element personnel is located in the fore deckhouse. This area involves a protected seating area for troops as they are shuttled from the Sea Base to the shoreline in preparation for battle. SPHBs are used to transport the troops the rest of the way to the treeline. The fore deckhouse also houses the crew, control center, and pilothouse for the ship. The required crew is small and the ship is to be operated by MSC. An aft deckhouse is used to house machinery systems as well as inlets and exhausts.

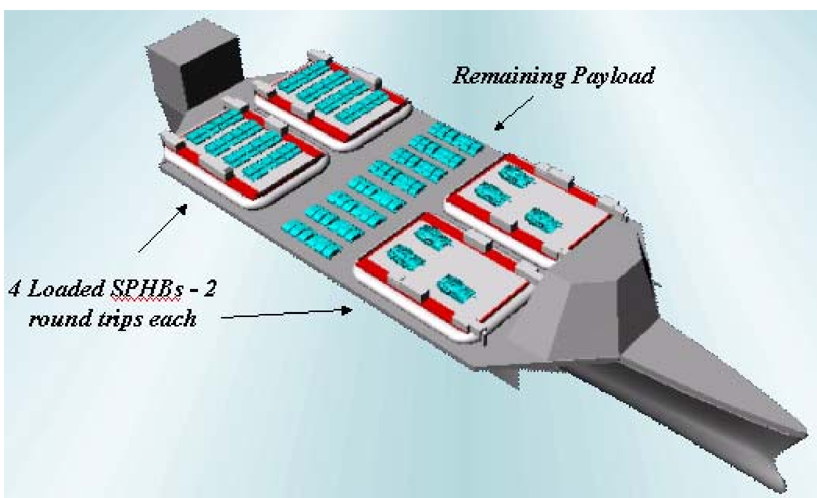

Figure 22 - HLT Deck Arrangement

Weights

The HLT weight breakdown was estimated by scaling R/V Triton weight data and making necessary adjustments for hullform modifications and heavy lift technology. The lightship weight is approximated as 20,000 metric tons, and the full load displacement is approximated as 26,000 metric tons. A large amount of fuel enables HLT to achieve an endurance range in excess of 2,000 nm. The SWBS breakdown is presented in Table 8.

Table 8 - HLT Weights

SWBS	Name	Weight (mt)
100	Hull	12,200
200	Propulsion	1,300
300	Electrical	2,200
400	Control & Communications	200
500	Auxiliary Systems	800
600	Outfit & Furnishings	2,700
800	Fuel/Misc. Loads	2,500
	MEB/SPHB Vehicles	3,100
	Summary	
	Lightship Weight	19,400
	Margin	1,000
	Lightship Weight + Margin	20,400
	Full Load Weight	26,000

Hydrostatics and Stability

The HLT hydrostatics and stability analyses were performed with the assistance of HydroMax, which is a subcomponent of MaxSurf. A few general values are listed in Table 9, and a detailed report can be found in Appendix B.

Table 9 – HLT Hydrostatics Characteristics

Parameter	Value
Vertical Center of Gravity	13.5 m
Design Draft	12 m
GM_T at Design Draft	2.0 m
Displacement at Design Draft	26,000 mt
Roll Period at Design Draft	12 sec
SPHB Ballast Condition Draft	19 m
GM_T – Ballast Condition	9.5 m
Displacement – Ballast Condition	51,500 mt
Roll Period – Ballast Condition	5.5 sec

One of the HLT design goals was to obtain a roll period of approximately twenty seconds in the ballasted condition (draft of 19 meters and 2 degree list). This goal was not achieved due to project constraints, and should be examined next time around the design spiral. The roll period approximation equation is shown below and was obtained from Rawson and Tupper's "Basic Ship Theory[8]":

$$T = 2\pi \frac{K}{\sqrt{gGM_t}}$$

Large Angle Stability analysis was also performed using HydroMax, and the results are presented in Appendix B. The righting arm (GZ) curve for full load displacement (26,000 MT) is shown in Figure 23, but a heeling arm curve was not calculated due to project constraints and the lack of proper evaluation tools. The heeling arm curve must be calculated in the future in order to check stability criteria.

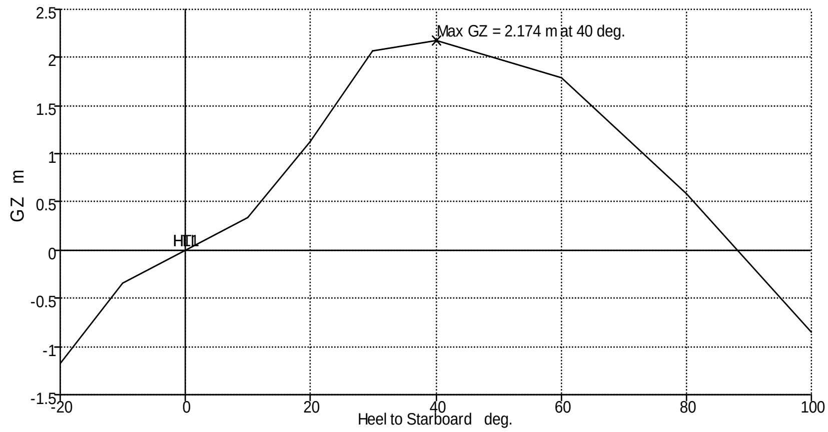

Figure 23 – HLT Large Angle Stability Analysis

Power and Propulsion

According to the Event Model, the HLT is required to have a sustained speed of 24 knots. This is a substantial improvement over traditional monohull HLS designs, which generally move at speeds between 10 and 15 knots. High speed is important because it allows cargo to be transferred great distances in short periods of time. Higher speeds are achievable, but the cost of reaching these speeds greatly outweighs the gains. For example, increasing sustained speed from 24 knots to 30 knots has a minimal effect on mission time, as shown in Figure 24, but a six-knot increase in speed would require an increase in power of approximately 30 MW (See Figure 25). Such a large increase in powering requirements could not be justified for the minimal gains in effectiveness of a six-knot increase in speed.

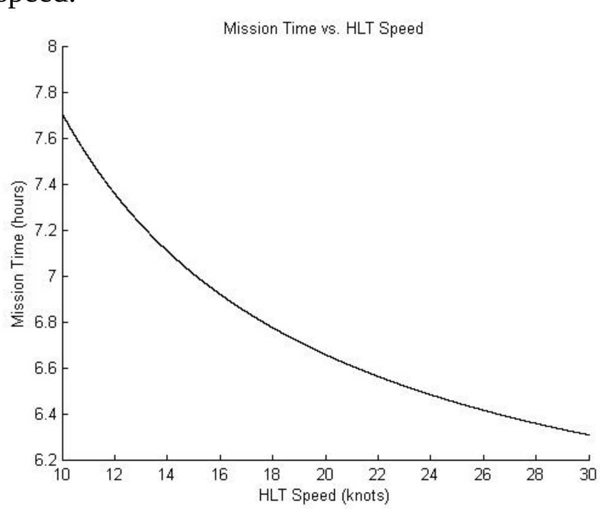

Figure 24 - Mission Time vs. HLT Speed

Powering and propulsion requirements were calculated using two different methods as shown in Figure 25. The first method involved scaling trimaran model test data to the HLT displacement to calculate required shaft power (SHP). HLT displacement, appendage drag, air drag, and a power margin were input into the trimaran model test spreadsheet to produce power versus speed curves for various propeller placements in the light and heavy displacement conditions. This approach yielded a SHP requirement of 38 MW for a sustained speed of 24 knots. This power requirement was confirmed using HullSpeed, another subcomponent of the MaxSurf package. In HullSpeed, the Holtrop and Fung displacement methods were used to estimate the power versus speed curve. These two methods are the most accurate methods for calculating multi-hull resistance. The SHP requirement for HLT as calculated by HullSpeed was generally in agreement with the trimaran model test data, as shown in Figure 25.

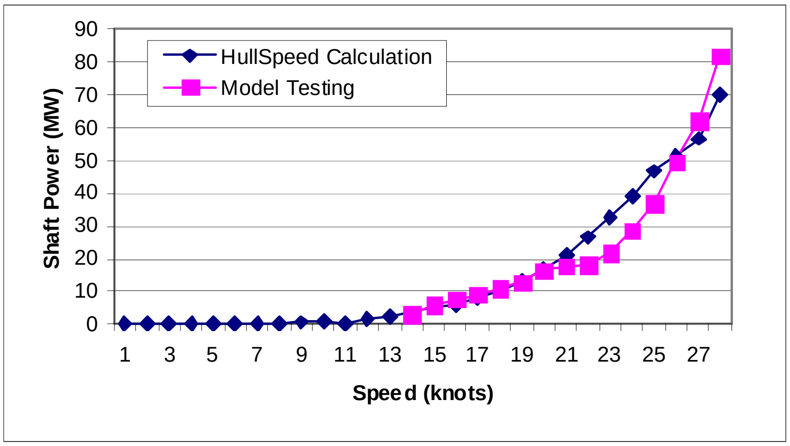

Figure 25 - HLT SHP vs. Speed

Sustained speed typically requires 80% of the maximum installed power. Total installed power, found to be 48 MW, was calculated using the following equation:

$$P_T = 1.25 * SHP$$

Providing 48 MW of power is easily achieved using diesel engines or gas turbines. A few prime mover possibilities are listed below:

1. Two PC 4.2 V18 Domestic Diesel Engines - 44 MW
2. Two Sulzer 7RTA-84C Foreign Diesel Engines – 54 MW
3. Two GE LM2500+ Gas Turbines – 54 MW

Self-Propelled Hover Barge

Principal Characteristics & Features

Cargo deck area was the driver of SPHB dimensions and design. The optimal cargo deck area was determined using the event model to maximize the throughput rate of the HLT/SPHB system. Once the cargo deck area was determined, the total deck area was calculated using a cargo deck area to total deck area ratio of 75% percent. This is a realistic estimate, and it is similar to other conventional hover barge designs. This ratio is also 25% higher than that of the LCAC. Another design driver was the requirement to achieve a ground contact pressure of around one pound per square inch when on cushion.

These factors were re-examined during each design iteration due to their importance on mission effectiveness and vehicle functionality.

The total length and beam of the craft had to be designed to fit within a length to beam ratio between one and two. For design simplicity, the air cushion was assumed to be the same size as the deck. SPHB general dimensions are specified in Table 10.

Table 10 - SPHB Characteristics

Parameter	Value
Length	**31 m**
Beam	**23 m**
L/B Ratio	**1.34**
Total Deck Area	**737 m**
Cargo Deck Area	**553 m**
Cargo Area/Deck Area Ratio	**75%**

SPHB is currently envisioned without combat systems, classifying it as a commercial vehicle. However, the design could easily be altered to include gun turrets or other small weaponry systems.

Weights and Loading

To achieve mission through-put requirements, the SPHB is required to carry a great deal of cargo. SPHB is able to transport three M1A1 tanks in the full load condition, and four tanks in the overloaded condition (Figure 26). This high load capacity enables a strong MEB surface force to be delivered to the treeline in one trip. Delivering four tanks to the treeline at one time would enable Marines to immediately secure a beach and rapidly create strong offensive capabilities. A load capacity of 265 metric tons enables the delivery of such a force. Weight estimate parametric equations were taken from Peter Mantle's "Air Cushion Craft Development" and adjusted slightly to accommodate SPHB mission particulars (Table 11). Specifically, the structural weight was increased to provide the structural integrity to support a payload of 265 metric tons. SPHB structure is likely to be rugged aluminum. The propulsion system weight was also increased to compensate for the marine screw and tracked systems. Adjustments had to be made because the Mantle equations reflect a light, high-speed hovercraft rather than a low speed hover barge.

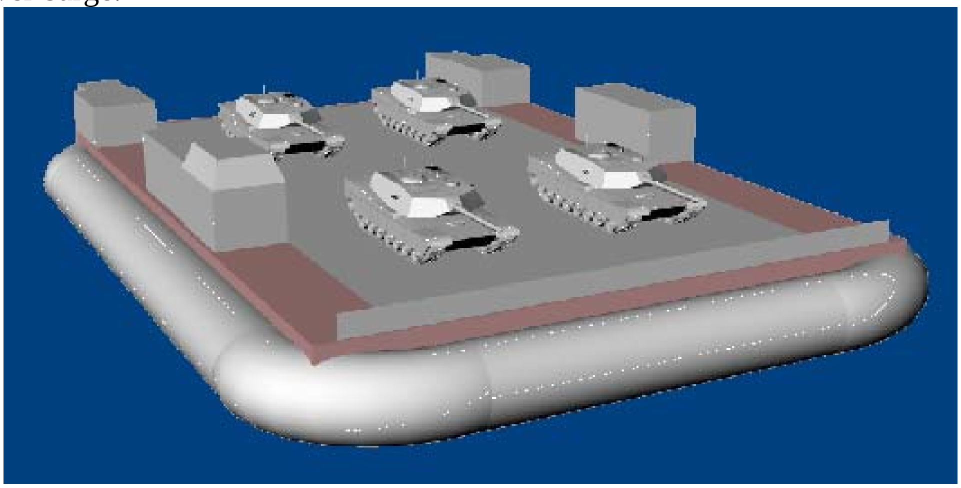

Figure 26 - Loaded SPHB

Table 11 - SPHB Weights

Weight Group	Mantle Equations	Adjusted Equations	SPHB Weights, MT
Structural	25% of All-up Weight (W)	33% of W	175
Propulsion	6% of W	1% of W	54
Electrical	1% of W	1% of W	5
Aux. Systems & Outfitting	3% of W	3% of W	11
Lift System	3% of W	3% of W	15
Total Payload	62% of W	50% of W	265
All-up Weight			525

Optimal loading cases and configurations have not been determined yet. However, SPHB has the ability to support a total payload of 265 MT, 210 MT of which is military cargo. The remaining 55 MT would consist of other loads such as fuel. The SPHB also has the ability to transport four M1A1 tanks or the equivalent payload of around 260 MT in the overload condition.

Hydrostatics & Stability

At this point early in the design process, a complete hydrostatics and stability analysis has not been completed due to the lack of a developed and detailed hullform. The SPHB should be sea state 4 capable to meet the design requirements. Therefore, it must be able to operate in 6-8 foot waves, 17-21 knot winds, and an 8.8 modal wave period.

The reduced speed of the SPHB increases its seafaring ability. One of the problems that has adversely affected the LCAC and other high-speed hovercraft is cushion washout. Cushion washout occurs when hovercrafts travel at high speeds and hit a wave, collapsing part of the skirt and reducing cushion pressure and hover height. At lower speeds, cushion washout is not as big of an issue. Also, the hover height of the SPHB has been set to four feet, the same as the LCAC. This will allow the SPHB to have at least the same sea state capabilities as the LCAC. However, SPHB sea state capabilities are likely to be improved due to the improvements with cushion washout.

The SPHB also has the ability to float as a displacement vessel and propel via marine screws when off cushion. As a result, the SPHB is still able to proceed back to the HLT or Sea Base if it is damaged or if lift failure occurs.

Power and Propulsion

A self-propelled hover barge was chosen for further research because of its versatility and independence. With a winched hover barge, complications with set-up make an eight-hour mission time hard to accomplish. SPHB speed was set as eight knots to reduce propulsion system size and cost. This speed also allows the mission to be accomplished quickly as long as the SPHB is relatively close to the shore. Figure 27 illustrates total mission time versus SPHB speed.

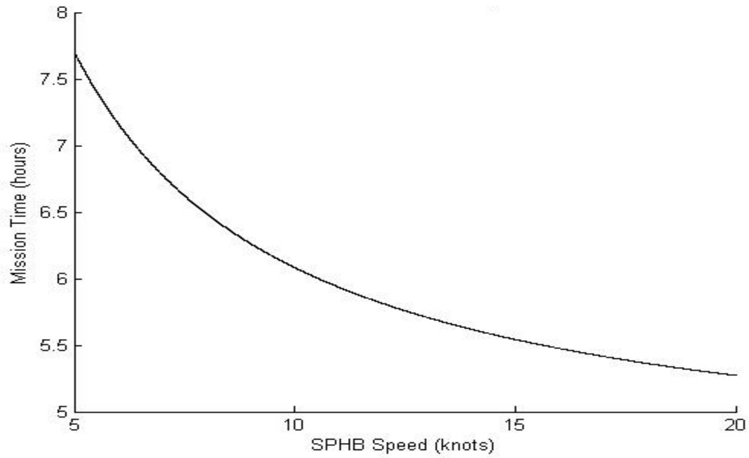

Figure 27 - Mission Time vs. SPHB Speed

A dual propulsion system consisting of retractable marine screws and a retractable track system was chosen because of their increased efficiency and control properties. Air screws provide about 3 pounds of thrust per horsepower, while a marine screw propulsion system offers 15 pounds of thrust per horsepower and land propulsion systems provide 20-30 pounds of thrust per horsepower. Thus, the SPHB dual propulsion system requires less horsepower than an equivalent air screw system. It also offers contact points with the ground or water, unlike the LCAC, increasing craft maneuverability. The 1985 LAMP-H study[1] performed by Band Lavis and Associates (now CDI Marine) also concluded that the most feasible propulsion system for a heavy lift hovercraft would be a dual propulsion system consisting of marine screws and a track system.

A tracked system was chosen for its versatility and reliability on a variety of surfaces. A wheeled system was also considered, but it could not provide the thrust required to climb a ten-degree slope at eight knots. A wheeled system would also require extremely large wheels, and the ground contact pressure would be much higher than that of a track system. Although the dual propulsion system is designed to achieve eight knots, it is feasible that the SPHB could reach speeds above 15 knots in low sea states or on flat surfaces.

SPHB powering is envisioned as either diesel engines or gas turbines supporting an Integrated Power System (IPS). IPS would provide electrical power to all vessel systems, including lift fans, marine screws, track systems, and other auxiliary systems. IPS works especially well with a dual propulsion system because power can be diverted to each system as needed. This saves space and reduces cost by eliminating individual power generators for each system.

Powering requirements for the SPHB lift system were calculated according to a parametric equation in Peter Mantle’s “Air Cushion Craft Development.” A hovercraft’s lift power requirement ranges from two to seven horsepower per ton. This value is multiplied by the vessel’s full-load weight, resulting in the required lift power. The parametric equation used was for a low speed hovercraft and is:

$$P_{Lift} = k_s W^{\frac{2}{3}}$$

SPHB water propulsion requirements were calculated according to the equations for hovercraft drag over water in Peter Mantle's "Air Cushion Craft Development." These equations resulted in a value in pounds of force, which was then divided by 15 pounds of force per horsepower to yield the horsepower required to achieve 8 knots over water. The 15 pounds of force per horsepower value is the amount of thrust provided by a traditional water propulsion system. Interaction with rough waves and high-speed winds was not accounted for; the power requirement is for an ideal surface with no winds. Dynamic stability was also not accounted for at this time. These conditions were not accounted for because the land thrust requirement drove the SPHB propulsion requirements, as explained in the following paragraphs. Equations for total drag and its subcomponents are as follows:

$$D_{Total} = D_{Aero} + D_{Momentum} + D_{Wave} + D_{Skirt}$$

$$D_{Momentum} = \rho Q V$$

$$D_{Aero} = \frac{1}{2} C_D \rho V^2 A_{Frontal}$$

$$D_{Wave} = \frac{2\left(Pc/L\right)^2 L^3}{\rho_w g \, L/B}\left[1 - \cos\left(\frac{1}{F^2}\right)\right]$$

$$D_{Skirt} = 1.374 D_W \left(Pc/L\right)^{-0.259} - D_W + 0.0058 W \left(h/C\right)^{-0.34}\left(\frac{1 + L/B}{\sqrt{L/B}}\right) K$$

The powering for the land propulsion system was calculated according to equations in M.G. Bekker's "Introduction to Terrain Vehicle Systems[2]." First, the required drawbar pull was calculated for the vehicle to travel up a ten-degree gradient at eight knots. This is the maximum power requirement for the vehicle, just like the LCAC. Power was then calculated in accordance with the following equations:

$$DP_{\mathrm{Re}quired} = W \sin(10)$$

$$P_{Land} = \frac{DP_{\mathrm{Re}quired} V}{550}$$

After analyzing initial data, the decision was made to have the SPHB reduce air cushion lift on land to become an "air-assisted" vehicle. On land, approximately one-third of the weight is supported by the track system and the other two-thirds is supported by the air cushion system. This was done in order for the track system to provide the necessary tractive force or drawbar pull. If air cushion support is lost, SPHB could be fully supported by its track system, and it would still be able to operate on all but the

softest of surfaces. Drawbar pull (DP) is equal to the track thrust (H) minus the soil resistance (R). The drawbar pull equation was implemented into MATLAB and used to calculate the required track system area. Ground contact pressure and track sinkage (Z) were also taken into account to improve accuracy. Equations used are listed below, and the following coefficient values for dry sand were found on page 240 of M.G. Bekker's "Introduction to Terrain Vehicle Systems[2]":

$$DP_{\Pr ovided} = H - R$$

$$H = A * c + W \tan(\vartheta)$$

$$R = \frac{1}{(n+1)(k_c + b * k_\vartheta)^{1/n}} \left[\frac{W}{L}\right]^{\left(\frac{n+1}{n}\right)}$$

$$Z = \frac{\left(W/_{b * L}\right)}{(k_c + b * k_\vartheta)^{1/n}}$$

Where: A = total track area
b = track width
L = track length
c = coefficient of soil cohesion (dry sand) = 0.15
ϑ = angle of soil friction (dry sand) = 28
n = exponent of soil deformation (dry sand) = 1.1
k_c = cohesive modulus of soil deformation (dry sand) = 0.1
k_ϑ = frictional modulus of soil deformation (dry sand) = 3.9

Table 12 outlines all of the general specifications calculated regarding the propulsion system. These features are illustrated in Figure 28.

Table 12 - SPHB Power & Propulsion Characteristics

Parameter	Value
Sustained Speed	8 knots
Lift Power Required	1.5 MW
Water Propulsion Power	0.25 MW
Land Propulsion Power	3.75 MW
Individual Track Length	25.3 m
Individual Track Width	1.6 m
Track Sinkage	3.6 cm
Ground Contact Pressure (Track)	3 psi
Ground Contact Pressure (Cushion)	1.05 psi

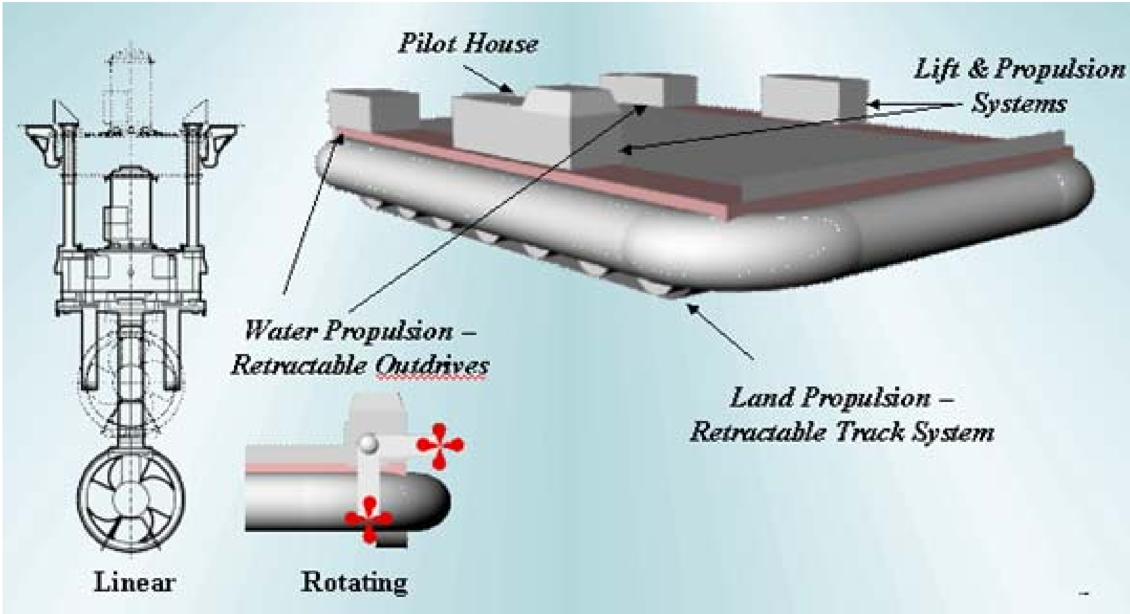

Figure 28 - SPHB Propulsion Features

Conclusions and Future Work

Conclusions

It was determined that a combination of a "Sea Base to Beach" connector and a "Beach to Treeline" connector was the most efficient method of delivering the payload. A general summary of the proposed concepts is presented below:

- Sea Base to Beach Connector: Heavy Lift Trimaran (HLT)
  - 4 ships @ 24 knots each
  - Large Deck Area (6000 m^2)
- Beach to Treeline Connector: Self-Propelled Hover Barge (SPHB)
  - 4 SPHBs per HLT (16 total)
  - 8 knots each
  - 550 m^2 cargo capacity
  - Capable of traveling over unimproved beaches with 10 degree gradients
  - Short Range & Low Speed/Power requirements result in Reduced Fuel Consumption
  - Limited Machinery/Communication Systems result in Reduced Cost

This system achieves the goal of delivering the MEB surface element in less than 8 hours (6.5 hours). This is equivalent to using 25 LCAC vehicles.

Future Work

There is some future work that must be done to further refine the concepts into feasible designs. This includes:

1. Heavy Lift Trimaran (HLT)

- Further hullform design and refinement to reduce draft and increase roll period
- Complete Stability Analysis
- Structural Analysis to reduce structural weight
- Propulsion Plant Selection
- Cost Analysis

2. Self-Propelled Hover Barge (SPHB)
   - Further Hull and Skirt Refinement
   - Structural Analysis
   - Directional Stability Analysis
   - Propulsion Plant Selection
3. Total Systems
   - Cargo Loading Plans (Arrangements and Time)
   - HLT and SPHB interfacing

S & T Issues

Some of the science and technology issues facing the HLT/SPHB system include:

1. Heavy Lift Trimaran (HLT)
   - Further refinement in general large-scale trimaran design
   - Integration of HLS technology with a trimaran hullform
   - Development of hinged or welded decks
   - Trimaran resistance and powering
   - Trimaran hull form seakeeping analysis methods
   - Trimaran hull form structural analysis methods
   - Trimaran ship weight analysis methods
   - Trimaran hull form stability analysis methods
2. Self-Propelled Hover Barge (SPHB)
   - Variable Lift Capability
   - Retractable or Rotating Outdrives/Tracks
   - IPS Propulsion
3. Integrated electric power systems

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Appendix A – Assumed Payload (MEB Surface Element)

Item	Number	Length (m)	Width (m)	Height (m)	Weight (mt)	Total Payload (mt)
M1A1	14	7.93	3.66	2.63	57.22	801.07
AAAV	48	9.10	3.66	3.18	28.53	1,369.44
M88A1	1	8.21	3.38	3.40	48.93	48.93
M1097	99	5.01	2.18	2.59	3.86	382.34
M198	18	7.52	2.82	2.18	8.00	144.02
LVS Mk48	2	11.58	2.44	2.59	25.40	50.80
M101A2	20	3.73	1.91	2.13	0.63	12.64
M390	21	4.72	2.44	2.24	2.32	48.69
LAV	25	6.99	2.67	2.67	15.73	393.19
Mk1 GI Joe	2,226	1.50	1.20	2.00	0.20	445.20
FRKLFT	7	8.86	2.57	2.72	15.02	105.16
AVLB	1	9.67	3.60	2.25	54.70	54.70
MEWSS	3	6.99	2.67	2.67	15.73	47.18
MTVR	133	8.70	2.46	3.53	11.79	1,568.52
MRC	33	4.85	2.31	1.83	4.67	154.18
M9293/Q46	4	7.98	2.46	3.53	10.87	43.50
ABV	2	12.04	3.66	2.90	49.90	99.79
					TOTAL	5,769 mt

Appendix B – HLT Hydrostatics

ID	Heel to Starboard degrees	-20	-10	0	10	20	30
1	Displacement tonne	26007	26005	25997	26003	26023	26020
2	Draft at FP m	12.669	13.038	12.660	12.394	11.389	10.305
3	Draft at AP m	11.434	11.576	11.439	10.925	10.076	8.881
4	WL Length m	187.640	188.002	187.975	188.008	187.676	187.337
5	Immersed Depth m	11.736	12.512	12.635	12.522	11.772	13.033
6	WL Beam m	40.326	41.450	41.484	41.419	40.607	32.256
7	Wetted Area m^2	8714.982	7506.749	7520.044	7486.348	8671.811	11359.387
8	Waterpl. Area m^2	3765.528	3126.203	3106.252	3123.510	6724.869	6004.331
9	Prismatic Coeff.	0.596	0.617	0.628	0.617	0.596	0.581
10	Block Coeff.	0.383	0.434	0.429	0.434	0.164	0.200
11	LCB to zero pt. m	-108.966	-108.946	-108.968	-108.947	-108.890	-108.904
12	VCB from DWL m	4.349	4.719	4.784	4.723	4.360	4.172
13	GZ m	-1.179	-0.348	0.000	0.336	1.120	2.060
14	LCF to zero pt. m	-112.707	-113.561	-113.350	-113.567	-112.661	-115.291
15	TCF to zero pt. m	-8.232	-1.829	1.838	5.452	15.017	13.269

ID	40	60	80	100
1	26025	25975	25995	25981
2	9.325	7.068	-0.882	-22.059
3	7.715	3.214	-15.696	-38.709
4	187.096	186.858	189.269	190.053
5	14.706	20.624	27.041	30.449
6	28.271	23.979	21.775	21.367
7	12711.847	14515.728	15717.135	16876.798
8	5201.625	3481.759	3243.255	3228.211
9	0.579	0.583	0.581	0.584
10	0.213	0.266	0.222	0.200
11	-108.980	-108.938	-108.940	-108.893
12	4.378	5.099	6.087	6.872
13	2.174	1.787	0.581	-0.853
14	-115.498	-107.773	-104.818	-103.390
15	12.837	12.171	11.881	11.016

Appendix C – Acronym List

AAAV	Advanced Amphibious Assualt Vehicle
ABV	Assault Breaching Vehicle w/ Mine Plow Attachment
AVLB	K1 Armored Vehicle Launched Bridge
BLA	Band, Lavis and Associates
CISD	Center for Innovation in Ship Design
CONOPS	Concept of Operations
DDHLS	Double Decker Heavy Lift Ship
EFV	Expeditionary Fighting Vehicle
FRKLFT	10 ton Forklift
GM	Metacentric Height
HLS	Heavy Lift Ship
HLT	Heavy Lift Trimaran
HMMWV	Truck Utility, Heavy
IPS	Integrated Power System
ISO	International Organization of Standards
LAMP-H	Light Amphibious, Heavy-Lift
LAV	Light Armored Vehicle
LCAC	Landing Craft, Air Cushioned
LCM	Landing Craft, Mechanized
LCU	Landing Craft, Utility
LSV	Logistics Support Vessel
LVS MK48	Logistics Vehicle System with Trailer
M1A1	Main Abrams Battle Tank
M101A2	Trailer ¾ ton
M198	155mm Towed Howitzer
M390	Trailer 2 ton
M88A1	Tank Recovery Vehicle
MEB	Marine Expeditionary Brigade
MEWSS	Mobile Electronic Warfare Support System
MK1 GI Joe	Troops
MRC JTRS	Truck Cargo 5 ton w/ Fire Finder Radar
MSC	Military Sealift Command
MTVR	Medium Tactical Vehicle Replacement
MW	Megawatts
NASSCO	National Steel and Shipbuilding Corporation
NSWCCD	Naval Surface Warfare Center Carderock Division
PACSCAT	Partial Air Cushion Supported Catamaran
RORO	Roll on Roll off
RSLS	Rapid Strategic Lift Ship
SDHSS	Shallow Draft High Speed Ship
SES	Surface Effect Ship
SHP	Shaft Horsepower
SPHB	Self-Propelled Hover Barge
SWBS	Ship Weight Breakdown Structure